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A SIMPLE METHOD OF HEIGHT DETERMINATION USING FAN-BEAM SEARCH RADARS

NAVAL RESEARCH LABORATORY, WASHINGTON, D.C.

14 DECEMBER 1976

NRL Report 8088

A Simple Method of Height Determination Using Fan-Beam Search Radars

Ben H. Cantrell

Radar Analysis Staff
Radar Division

December 14, 1976

NAVAL RESEARCH LABORATORY
Washington, D.C.

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NRL Report 8088	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) A SIMPLE METHOD OF HEIGHT DETERMINATION USING FAN-BEAM SEARCH RADARS		5. TYPE OF REPORT & PERIOD COVERED Interim report on a continuing NRL problem
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Ben H. Cantrell		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Research Laboratory Washington, D.C. 20375		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NRL Problem R02-97 Program Element 61153N-21 Project RR021-05-41
11. CONTROLLING OFFICE NAME AND ADDRESS Department of the Navy Office of Naval Research Arlington, Va. 22217		12. REPORT DATE December 14, 1976
		13. NUMBER OF PAGES 9
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release, distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Search radars
Height measurements
Angular measurements

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A simple angle-measurement technique for a 2D search radar is described. Its features are accurate elevation and azimuth measurements which are only slightly effected by multipath and are roll and pitch tolerant. Furthermore, a radar using this technique can be constructed for a relatively low cost.

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A SIMPLE METHOD OF HEIGHT DETERMINATION USING FAN-BEAM SEARCH RADARS

INTRODUCTION

Radars are generally classed as 2D or 3D: the 2D radar has a fan beam which covers all elevations simultaneously, whereas the 3D radar usually has a narrow beam in both the elevation and azimuth plane and is often scanned in elevation. The 3D radar is usually characterized by good resolution, surface-induced multipath effects in only the lowest beam position, and high antenna gain. All of these properties are desirable. However few pulses are obtained on target, often multiple beams or radars are required, the antenna is larger than that of a 2D radar, and the cost is high. The 2D radar is usually lower in cost, has a smaller antenna, and has more pulses on target but suffers considerably due to ground-induced multipath. In addition, for shipboard applications, where the antenna is not stabilized, the 2D radar does not make accurate azimuth or elevation measurements due to the effects of multipath. These problems do not exist in general with 3D pencil-beam radars. The objective in this report is to describe a simple means of obtaining accurate azimuth and elevation measurements with a fan-beam radar in the presence of surface-induced multipath and ship's roll and pitch.

A few topics which are pertinent to the radar system description are reviewed briefly, and only the simple models are discussed. The proposed radar system is then given.

MULTIPATH MODEL USING GEOMETRICAL OPTICS

The radar antenna and a target are located above the sea surface as shown in Fig. 1. The radiation from the antenna to the target to the antenna and the backscatter from the target will both be propagated by the direct path and the reflected path. At each point on the antenna aperture the signal strength is the sum of the direct signal and the indirect signal, whose relative phase varies. The resultant returned signal is obtained by summing the signals across the aperture. The results of this simple model are well known [1] and are

$$S = A \left\{ G(e) e^{+j2\pi h_a e/\lambda} + \rho G(-e) e^{-j2\pi h_a e/\lambda} \right\}, \tag{1}$$

where

$G(e)$ - antenna pattern,
ρ - reflection coefficient,
h_a - antenna height,
e - elevation angle,
λ - wavelength,
S - returned signal, and
A - amplitude.

Manuscript submitted November 15, 1976.

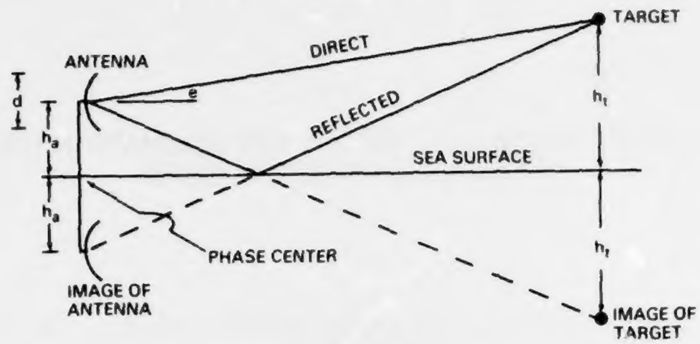

Fig. 1 — Multipath geometry

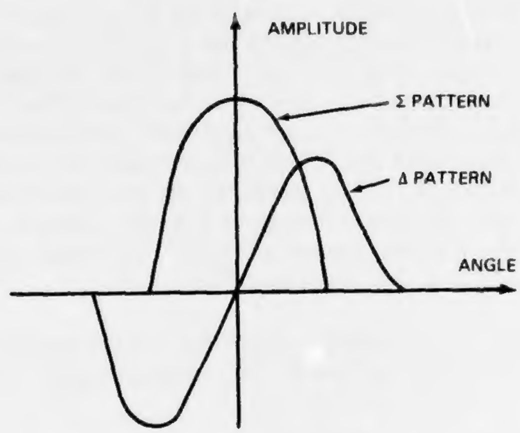

Fig. 2 — Sum (Σ) and difference (Δ) monopulse antenna patterns

Equation (1) shows that as the target elevation changes, the returned signal fluctuates due to the direct and indirect signal interfering (direct and reflected signal going in and out of phase). This simple model is sufficient for the remaining work in this report.

THE ANGLE-MEASUREMENT PROBLEM

Angle measurements are usually obtained from the radar beam patterns. For example a simple monopulse [1] radar computes the elevation angle by measuring the return from two patterns called the sum (Σ) and difference (Δ), shown in Fig. 2. A radar pointed toward the horizon would yield an elevation measurement using (1) in the form

$$\frac{S_\Delta}{S_\Sigma} = \frac{G_\Delta(e)}{G_\Sigma(e)} \; \frac{e^{+j2\pi h_a e/\lambda} - \rho e^{-j2\pi h_a e/\lambda}}{e^{+j2\pi h_a e/\lambda} + \rho e^{-j2\pi h_a e/\lambda}} \tag{2}$$

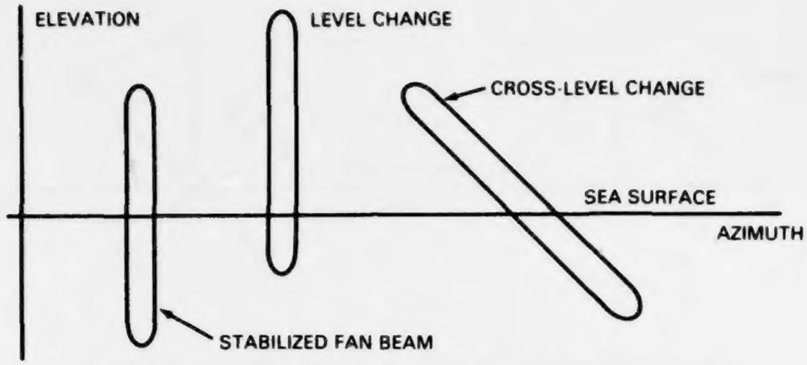

Fig. 3 — Three-dB contours of attena patterns showing the effects of level and cross-level changes

If the reflection coefficient ρ were zero, the target elevation is obtained by solving for the elevation e from $G_A(e)/G_\Sigma(e)$. However, if ρ is not zero, the signal S_A/S_Σ will yield large variations with only small changes in e. Of course this is the old and well-known glint and low-angle tracking problem. Other techiques have been considered [2] but are not discussed here.

EFFECTS OF ROLL AND PITCH

The effects of roll and pitch can be considered as a rotation of the beam in level and in cross level as shown schematically in Fig. 3. The level basically changes the elevation pointing direction of the beam, and the usual requirement imposed is simply to keep power propagating in the desired direction. The cross-level effects coupled with multipath effects are severe from the point of view of angle measurements. Consider a pencil beam centered on the horizon and a target above the horizon (Fig. 4). If the sea surface were not there and a free-space environment existed, both the angles along the elevation and the azimuth could be measured by normal monopulse techniques, and if the radar were rotated in cross level the measurements along e' and a' could be rotated to obtain the unrotated elevation and azimuth. If multipath exists and there is no cross level ($\psi = 0°$), the azimuth can be measured accurately. On the other hand elevation cannot be measured accurately due to the multipath changing the distribution of power across the aperture in the vertical direction. However, when cross-level rotations exist, the vertical distribution of power couples into both the e' and a' directions, yielding large errors in both. Often in narrow-beam 3D search radars these errors are tolerable, because the errors are less than a beamwidth. However for fan-beam radars the errors are not tolerable.

THE PROBLEMS

The problems with most fan-beam radars are fading due to multipath, poor angle measurements in elevation due to multipath, and poor azimuth measurements due to cross-level and multipath interactions. In the next section a radar system is proposed which should eliminate these problems.

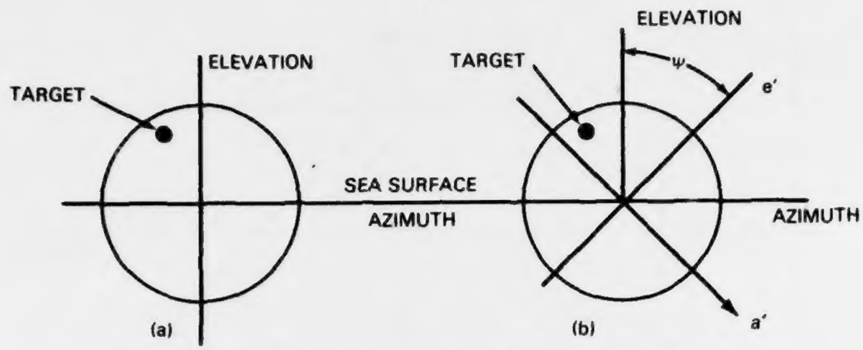

Fig. 4 — Measurement axes of a pencil-beam radar, showing target-angle measurements for two cross-level conditions; (a) $\psi = 0^\circ$ (no cross level), (b) $\psi = 45^\circ$

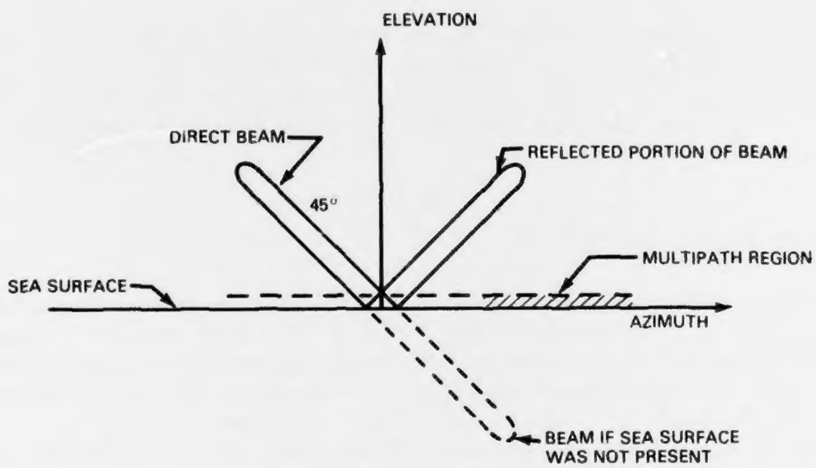

Fig. 5 — Formation of a V-beam from a fan beam by reflection off the sea surface

A PROPOSED METHOD OF IMPROVING ANGLE MEASUREMENT

The proposed radar has a fan beam with a narrow azimuth beam (approximately 1°) that is rotated at some chosen angle such as 45° to the vertical and centered on the sea surface (Fig. 5). The portion of the beam which would be below the horizon is reflected so as to form a V. The operation should not be confused with the operation of a conventional V-beam radar [1]. The reflected beam does not interfere with the direct beam except near the sea surface.

Any target in the direct beam above the multipath region can be monopulsed to find the angles (because no multipath effects are present), and then these coordinates can be rotated to find the true position. In addition there is no fading, due to the absence of interfering sea reflections. If the monopulse null is at the horizon, any negative angle corresponds to the target being in the reflected beam and a positive angle in the direct beam. The system is also fairly tolerant to roll and pitch. The cross level can change

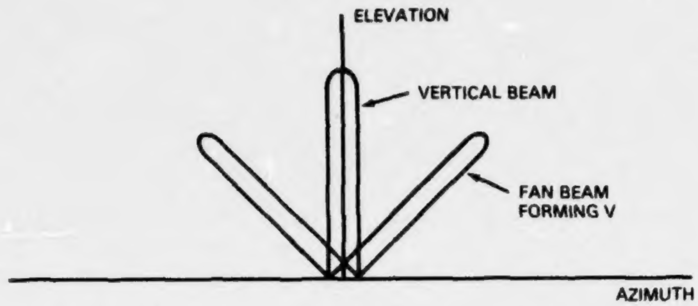

Fig. 6 — Receive-only vertical beam added to a tilted fan beam for determining that a target is in the multipath region

about 20° without substantially changing the result. Because the fan is broad, it is tolerant to level changes.

Any target in the region near the sea surface will experience severe fading due to multipath. This can be alleviated by using frequency diversity. The angle measurements will be grossly in error and will change dramatically from frequency to frequency and from scan to scan of the radar. The target could be said to be in this small region by noting this condition. Another means of showing that the target is in the multipath region is to introduce a receive-only beam in the vertical plane (Fig. 6). If the target is detected in both the tilted beam and vertical beam simultaneously, the target can be said to be in the multipath region.

SUMMARY

A means of obtaining accurate azimuth and elevation measurements under multipath and cross-level conditions for a fan-beam search radar was described. This was obtained by tilting a narrow fan beam, thus separating the reflected and direct signals except at the low elevation angles. The low elevation angles are taken into account by using frequency diversity of a receive-only beam tilted at a different angle from the main fan beam.

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